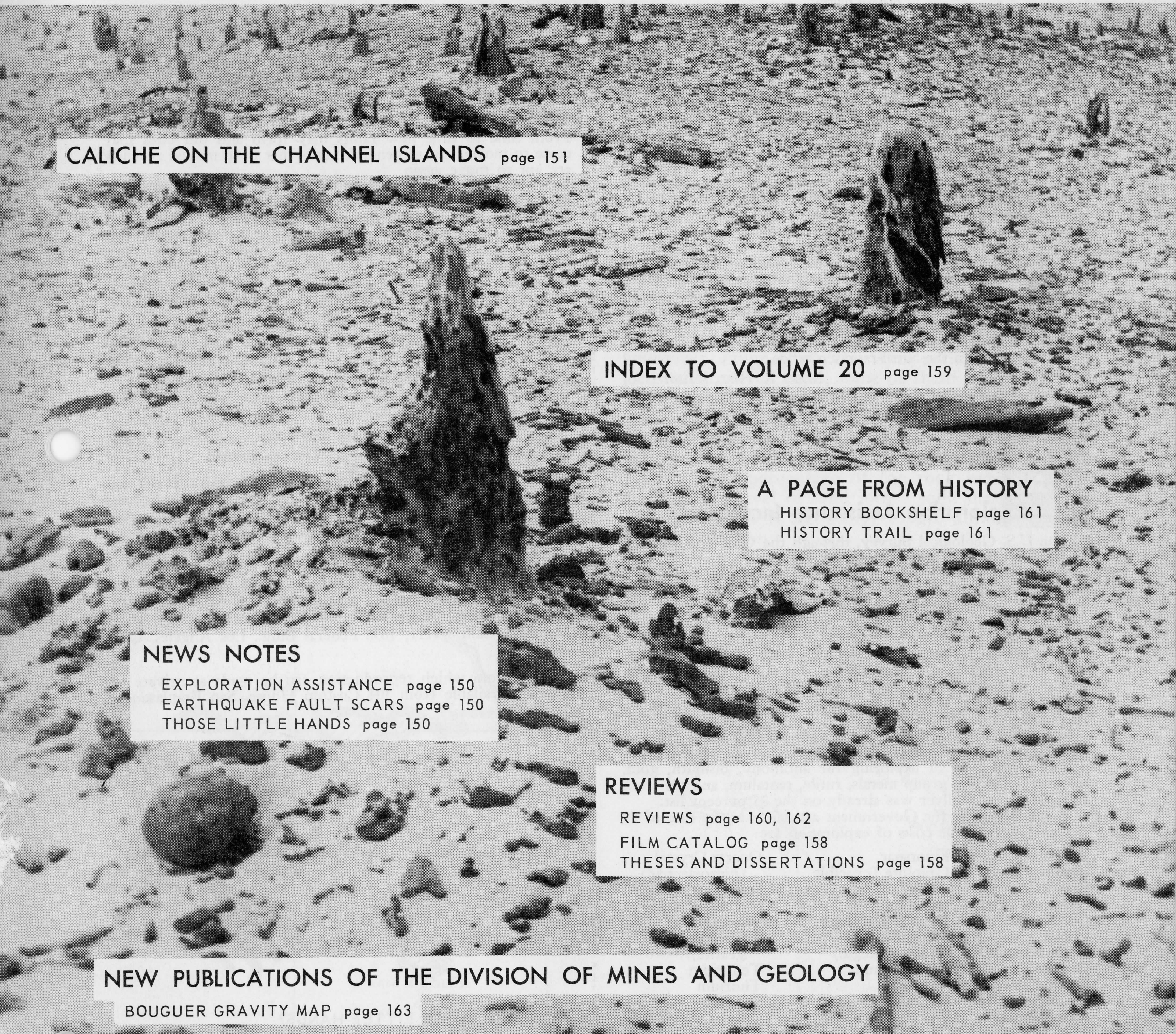
MINERAL INFORMATION SERVICE

A PUBLICATION OF THE CALIFORNIA DIVISION OF MINES AND GEOLOGY

VOLUME 20 NUMBER 12

DECEMBER 1967



STATE OF CALIFORNIA ▪ THE RESOURCES AGENCY ▪ DEPARTMENT OF CONSERVATION ▪ DIVISION OF MINES AND GEOLOGY

CALICHE ON THE CHANNEL ISLANDS

By Donald Lee Johnson

Donald Lee Johnson, a native Californian, is a Fellow at the University of Kansas whose interest in the Channel Islands stems from earlier field work initiated while at the University of California, Los Angeles. Soil and geomorphological problems on San Miguel Island will constitute the subject matter of his Doctoral dissertation . . . Edit.

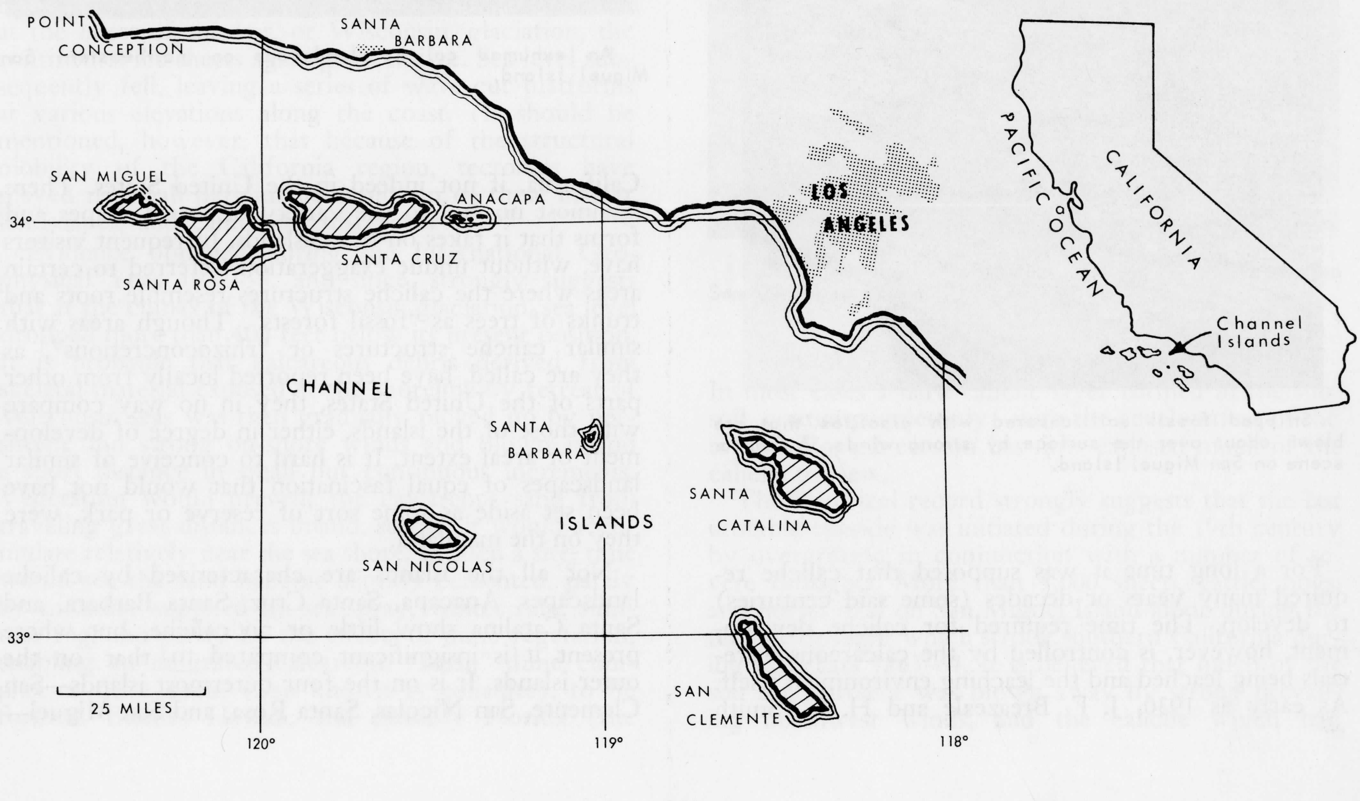
Many of the subhumid and arid regions of the world, including much of California, are characterized by surface and subsurface calcareous accumulations known in the United States as caliche. In other countries, caliche may be called kunkar, travertine, calcrete, croute calcaire, nari or oberflachenbreccie, or one of several other names, depending on the country. Although the caliche deposits in continental California are well known, those on the Channel Islands of southern California are less familiar.

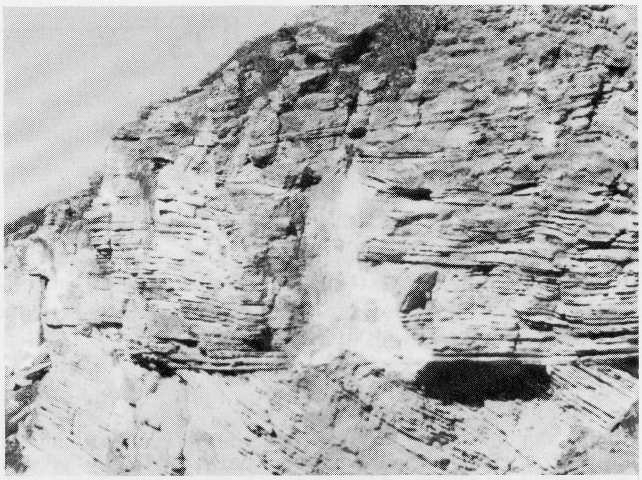
The word "caliche" comes to us from the Spanish and is derived from the Latin "calix", meaning lime. It was in general use in Mexico and southern Arizona as early as 1901, according to William P. Blake. Since then, the term has for the most part been used to describe calcareous deposits; but some authors have extended it to materials as unlike caliche as quartzite and kaolinite. Such indiscriminate and broad applications have seriously reduced the value of the term.

To complicate the matter, for many people "caliche" has certain genetic connotations, a factor which makes it difficult to define. However, some definition is necessary for our purpose; and the following best reflects technical usage in the United States.

> Caliche is an opaque, reddish brown to buff or white material of secondary accumulation in situ which is commonly but not invariably found as a subsoil deposit in subhumid to arid climates, and which is composed largely of calcium carbonate in addition to such clastics as gravel, sand, silt, and clay, which may be present in various proportions. Other compounds may or may not be present.

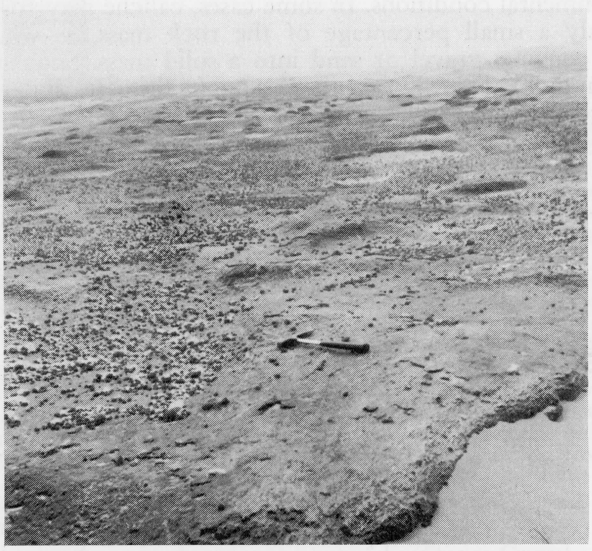
Caliche may be massive or stratified, or even laminated or banded—in which case it may resemble algal limestone. Rarely, it may form hollow tube- or pipe-like structures, some of which may later become solidly filled with concentric bands of caliche. It may, moreover, range from very thin surficial deposits to beds of great thickness, some of them measuring well over a hundred feet. Caliche also may be extremely porous and friable, or, conversely, impermeable and strongly indurated, depending on temporal and environmental conditions. In some cases, caliche may form only a small percentage of the rock mass, as when it cements gravel or sand into a solid mass. Such indurated caliche is frequently tough, durable, and resistant to erosion.





Cross-stratified Pleistocene eolianite on San Miguel Island showing dips up to 41°. Such fossil dunes occur in Australia, South Africa, Madagascar, Persian Gulf, the Mediterranean, West Indies, Bermuda, and Hawaii.

Caliche commonly, but not invariably, conforms to the topography upon which it is developed. In doing so, the caliche stratum may cut unconformably across bedding planes of underlying strata. Also, because steep slopes permit greater surface runoff after rains with a resultant decrease in leaching of carbonate, caliche tends to be thickest on gentle slopes and thin or absent on steep slopes.



Stripped fossil soil covered with pisolites that are blown about over the surface by strong winds. A familar scene on San Miguel Island.

For a long time it was supposed that caliche required many years or decades (some said centuries) to develop. The time required for caliche development, however, is controlled by the calcareous materials being leached and the leaching environment itself. As early as 1930, J. F. Breazeale and H. V. Smith cited cases in Tucson, Arizona, where pieces of gravel and brick had been cemented with caliche over a span of several years. They also described a case where a layer of caliche had formed a few inches below the surface of a regularly watered lawn in Tucson. As further evidence, they performed experiments whereby they induced accelerated caliche accumulations over a span of several weeks. Evidence found on the Channel Islands supplements the findings of Messrs. Breazeale and Smith regarding the rapidity with which caliche may form. This, of course, does not mean that in other environments a much longer time would not be needed.

Caliche on the Channel Islands. The surface expression of caliche on the Channel Islands is unique in

An exhumed caliche landscape on northeastern San Miguel Island.

California, if not indeed in the United States. There is almost no end to the variety of weird shapes and forms that it takes on these islands. Infrequent visitors have, without undue exaggeration, referred to certain areas where the caliche structures resemble roots and trunks of trees as "fossil forests". Though areas with similar caliche structures or "rhizoconcretions", as they are called, have been reported locally from other parts of the United States, they in no way compare with those of the islands, either in degree of development or areal extent. It is hard to conceive of similar landscapes of equal fascination that would not have been set aside as some sort of reserve or park, were they on the mainland.

Not all the islands are characterized by caliche landscapes. Anacapa, Santa Cruz, Santa Barbara, and Santa Catalina show little or no caliche, but where present it is insignificant compared to that on the outer islands. It is on the four outermost islands—San Clemente, San Nicolas, Santa Rosa, and San Miguel—

that deposits of caliche reach bizarre proportions. Indeed, on San Miguel Island it is difficult to find a spot that lacks either subsurface or surface caliche accumulations. On the northern and western parts of the island, tough case-hardened caliche makes up much of the ground cover and gives rise to an exceptionally lifeless-appearing landscape. If one can imagine a ground surface of caliche resembling rough chunks and slabs of hardened plaster of Paris upon which great semi-indurated fossil sand dunes are intermittently located, and upon which are found also scattered stands of caliche fossil forests, he will gain a vicarious approximation of what the actual landscape is like. Similar though less bizarre landscapes are found on the western end of Santa Rosa Island, over the southern and western portions of San Nicolas Island, and the northwestern coast of San Clemente Island.

When one first views these striking landscapes, several questions immediately come to mind. How did such odd landscapes originate? What was the source of such incredible quantities of calcium carbonate? Why were only the four outermost Channel Islands affected?

There are no simple and no final answers to the above questions. Research conducted to date, however, does suggest that the evolution of these insular landscapes has consisted of a long and complex series of events that may have been initiated at the onset of the time of the Sangamonian Interglacial, perhaps as much as 100,000 years ago or more. At that time the ice composing the Illinoian ice sheets had shrunk to a mass less than the volumes which now comprise Greenland and Antarctica. In consequence of the melting Illinoisan glaciers, sea level rose to a point higher than at present, perhaps by as much as 100 feet. Then at the onset of the last, or Wisconsin, glaciation, the continental ice sheets again grew in size. Sea level subsequently fell, leaving a series of wave-cut platforms at various elevations along the coast. (It should be mentioned, however, that because of the structural mobility of the California region, tectonics have played no small part in the evolution of these insular landscapes, and cannot be disregarded.)

Evidence obtained during the International Geophysical Year 1957–58, and since, strongly suggests that at the climax of the Wisconsin glaciation, sea level dropped more than 400 feet below its present position. It is probable that calcareous debris derived from skeletal material exposed at the shoreline by retreat of Wisconsin seas was then gradually picked up by persistent and strong on-shore winds and blown inland a short distance in small but continuous increments. Vegetation would prevent the calcareous sand from traveling great distances inland, so that it would accumulate relatively near the sea shore. In such a site, time would see the sand become slightly cemented, partly by moisture supplied by sea spray, winter rain, summer fog, and partly by the effects of dune vegetation, enabling an indurated calcareous "fossil" dune complex or dune rock, (also known as eolianite), to be formed. Besides Hawaii, and possibly Florida (the Miami oolite may be in part eolian, according to Rhodes Fairbridge) the only known calcareous eolianites in the United States are on the Channel Islands.

Stable and unstable periods alternated, as shown by the presence of ancient soil bands, or paleosols, intercalated with eolianite. Small plants, shrubs, bushes, and trees, of species as yet unidentified, grew in profusion and added dark humus matter to the soils. Vegetation was obviously overwhelmed by blowing sand, for buried tree trunks now in the form of caliche casts are found where presently there is no vegetation. On San Miguel Island, at least five such episodes of blowing sand occurred; there is evidence of several episodes on San Nicolas, Santa Rosa, and San Clemente Islands.

Former tree trunks calichified in eolianite, northwestern San Clemente Island.

In most cases a hard caliche layer formed in the subsoil contemporaneously with the development of the topsoil. Recent erosion has now exposed much of the caliche to view.

The historical record strongly suggests that the last unstable episode was initiated during the 19th century by overgrazing in conjunction with a number of severe droughts. More than 5,000 sheep, cattle, hogs, and horses died on San Miguel Island alone during the terrible drought which struck southern California during the years 1863–64. It is believed that much of the soil then present was blown away by strong prevailing northwest winds, and the caliche which had

formed both beneath the topsoil and within the eolianite was subsequently exposed.

Although caliche is found in an almost endless profusion and variety of forms on the islands, these forms may be grouped into two main types—soil caliche, and eolianite caliche. The eolianite caliche may be further divided into surface case-hardened caliche and rhizoconcretions, and the rhizoconcretions into hollow root sheaths and filled root, trunk, and stem casts. Each of these types is formed by somewhat different genetic processes.

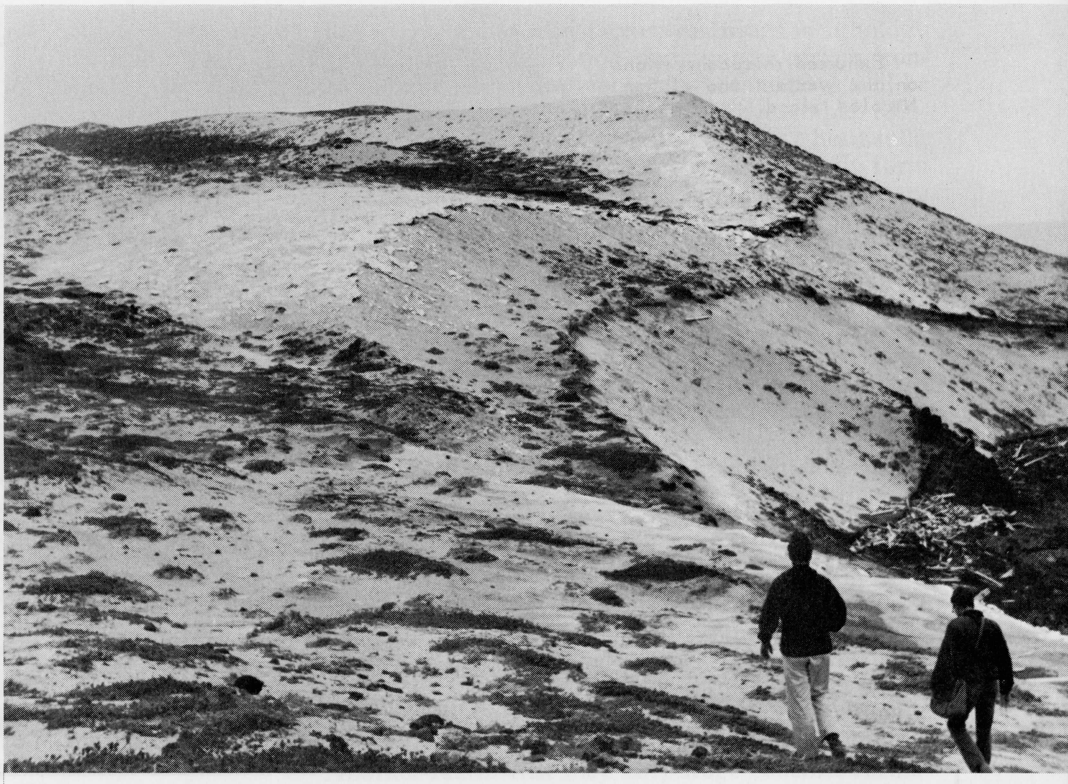
A most remarkable Pleistocene paleosol, comprised almost entirely of pisolites, well leached and developed on eolianite parent material. Complete laboratory analyses will provide valuable insight on its age and genesis, and paleoclimatic conditions at time of formation. San Miguel Island.

Soil caliche. In areas with subhumid to arid climates, particularly where distinctly seasonal rainfall occurs in amounts less than about 30 inches, calcium carbonate, if present, is leached from the topsoil and deposited in the subsoil or substrate as caliche. In areas of high rainfall, as in the eastern United States, carbonates are, of course, leached out of the soil and into drainage systems. The mechanisms involved in rendering calcium carbonate soluble and leading subsequently to precipitation are well known. Rain picks up CO_2 in falling, thus forming small amounts of carbonic acid. Much more carbonic acid is formed when rain water joins with carbon dioxide given off by plant decay in the soil. Calcium carbonate present at or near the soil surface is then taken into solution as a bicarbonate $[CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2]$ by the carbonic acid, and is carried downward; and, upon evaporation or loss of carbon dioxide, is later precipitated at the general level to which rain water may penetrate. When the soil parent material is calcareous eolianite, as on the Channel Islands, unusually thick caliche accumulations may result.

Eolianite caliche. In certain areas on the northwest coast of San Clemente Island and the northern part of San Miguel Island, initial observation suggests that caliche formed directly upon the undulating surfaces of former dunes. Closer inspection, however, reveals that the caliche horizon represents a relict soil hardpan which became casehardened after the surface soil was stripped away during an unstable episode. Winter rain, seaspray, and summer fog aided casehardening through solution and redeposition. After the initiation of such casehardened topography, each succeeding rainfall or moist period served to further the lithification of the former dune surfaces. Sufficient time elapsed to allow thorough casehardening of the eolianite surfaces before they were buried by new dunes. Such relict casehardened surfaces now appear as caliche bands interbedded with calcareous eolianite and serve to outline the former dune topography. Caliche casehardening locally is still active today on the outermost Channel Islands.

Fossil forests are believed to have originated from two dissimilar processes. Both the hollow and solid caliche rhizoconcretions, although sometimes called "pedotubules", are generally referred to as "root casts". Though root casts are present, the hollow forms are not really casts at all, but are more correctly called "root sheaths". Root sheaths apparently form in one or more of five biochemical ways, dependent upon (1) the presence of organic acids exuded by living plant roots; (2) symbiotic relations between roots and certain soil bacteria; (3) symbiotic relations between roots and certain soil fungi; (4) the presence of some blue-green soil algae which have calcium carbonate-precipitating bacteria housed in their slime sheaths; (5) calcium exclusion properties of some plants which promote the precipitation of calcium carbonate outside the root. Although the possibility exists that any one or a combination of the above processes may result in the formation of caliche root sheaths, recent conversations with several plant physiologists lead me to the tentative conclusion that the first is probably responsible.

Former fallen tree still attached to base, now calichified. Attached liana-like vine encircling the trunk hints of an earlier climate more humid than now. San Miguel Island.



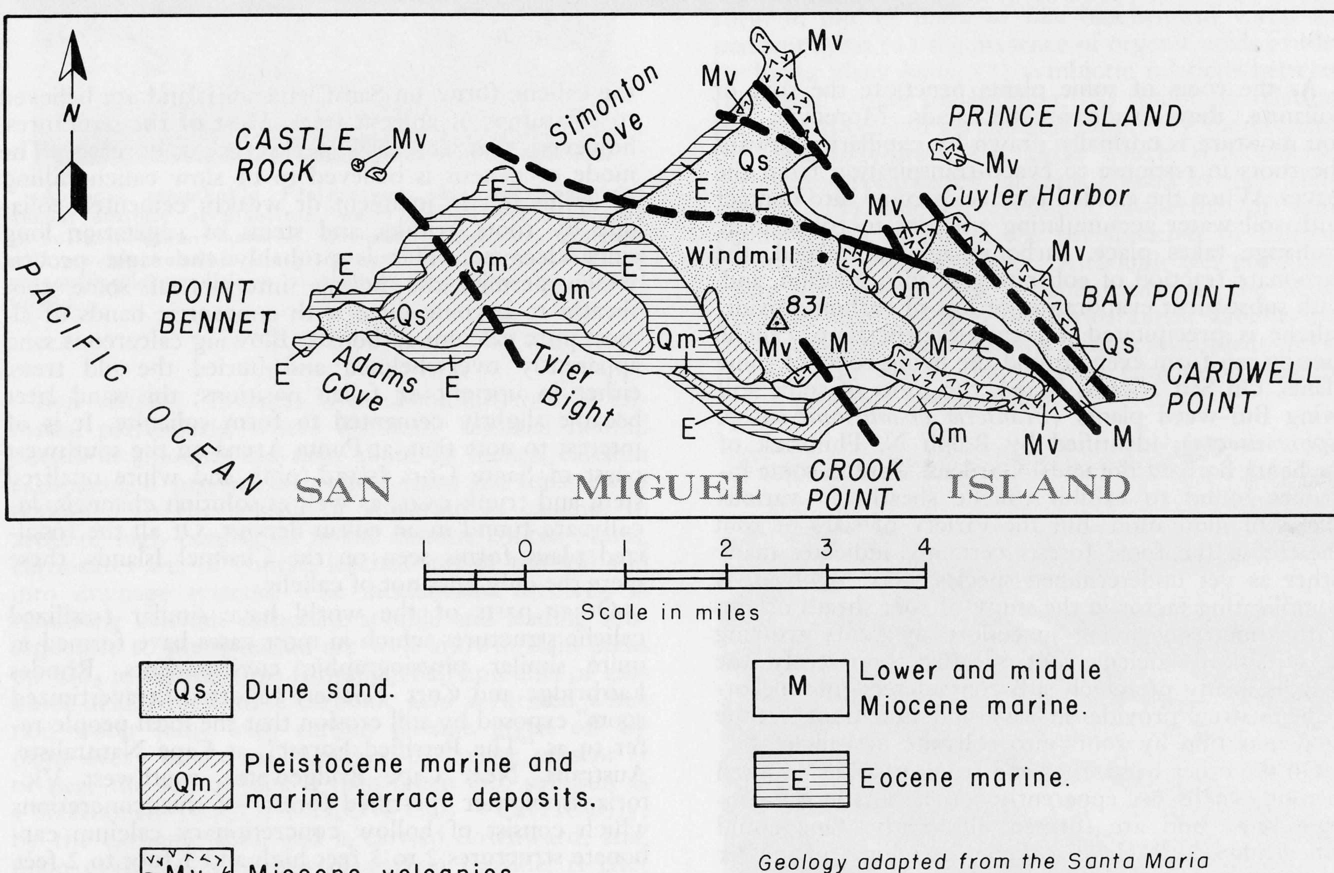
Casehardened caliche in eolianite reflecting the undulating relict topographic surfaces, northwestern San Clemente Island.

As the roots of some plants penetrate the soil, or eolianite, they exude organic acids. Moreover, the soil moisture is normally drawn by capillarity toward the roots in response to evapo-transpiration from the leaves. When the exuded root acids come into contact with soil water accumulating adjacent to roots, ionic exchange takes place, carbonic acid is formed, the carbonate fraction of eolianite goes into solution, and, with subsequent evaporation or loss of carbon dioxide caliche is precipitated. Given sufficient time, caliche sheaths can form even around the living roots of some plants. On San Nicolas Island, the roots of some still living Bur-weed plants (*Franseria chamissonis* subsp. *bipinnatisecta*), identified by Ralph N. Philbrick of the Santa Barbara Botanical Gardens, were in some instances found to exhibit caliche sheaths in various stages of induration. But the variety of sizes of root sheaths in the fossil forests certainly indicates many other as yet undetermined species were involved. A complicating factor in the study of root sheath origins is the numerous living juvenile plant roots growing in obviously ancient root sheaths. Apparently the sheaths, many of which still contain recognizable organic matter, provide an easy and nutritious avenue of penetration by roots into eolianite or caliche.

On the other hand, root and trunk casts, as opposed to root sheaths, are apparently actual casts in the geologic sense and are formed differently. One could conceivably call them caliche pseudomorphs after trunks and roots. Of the comparatively few examples of trunk casts found on the islands, the most unusual was a huge caliche log some 2½ feet in diameter and about 30 feet long, on San Miguel Island. Some of the caliche forms on San Clemente Island are believed to be stumps of ancient trees. Most of the structures, however, that are casts per se are root casts. The mode of genesis is believed to be slow caliche-filling of molds left in incipient or weakly cemented eolianite by roots, trunks, and stems of vegetation long since decayed. This is probably the same process which permits the hollow interiors of some root sheaths to become filled with concentric bands of almost pure calcium carbonate. Blowing calcareous sand apparently overwhelmed and buried the old trees, either in upright or fallen positions; this sand later became slightly cemented to form eolianite. It is of interest to note that, at Punta Arena on the southwest coast of Santa Cruz Island, pink and white opalized stem and trunk casts, as well as solution channels, locally are found in an eolian deposit. Of all the fossilized plant forms seen on the Channel Islands, these were the only ones not of caliche.

Other parts of the world have similar fossilized caliche structures which in most cases have formed in quite similar physiographic environments. Rhodes Fairbridge and Curt Teichert reported "travertinized roots" exposed by soil erosion that the local people refer to as "The Petrified Forest", at Cape Naturaliste, Australia. Near Cape Bridgewater, southwest Victoria, is another "petrified forest" of rhizoconcretions which consist of hollow concretionary calcium carbonate structures 2 to 3 feet high and 1 foot to 2 feet in diameter. The mode of origin of the latter is conceivably the same as that of the sheaths described above. Indeed, Professor Teichert of the University of Kansas recently described living trees with caliche en-

Exhumed rhizoconcretions on the western end of San Nicolas Island.



Geology adapted from the Santa Maria sheet of the Geologic Map of California, Division of Mines and Geology.

GENERALIZED GEOLOGIC MAP OF SAN MIGUEL ISLAND

crusted roots, which he found on Rottnest Island near Perth. E. M. Kindle in 1925 described a similar but small-scale occurrence near Ontario, Canada. Rhizoconcretions are also common along the shores of the Mediterranean.

Of the three questions initially posed, the last is the most provoking, and perhaps the most difficult—if not impossible—to answer: Why were only the four outermost islands—San Clemente, San Nicolas, Santa Rosa, and San Miguel—affected by caliche landscapes? Certainly low-level late-Pleistocene seas would have provided calcareous sand for eolianite to form along the shores of the mainland and on the other Channel Islands. It is significant, however, that no eolianite has yet been reported from the mainland or the inner islands. Again, why?

It seems very probable that all or a certain combination of the following factors, in various proportions, were responsible for the formation of calcareous eolianite on the outermost Channel Islands during late Pleistocene times, and that an absence or incorrect combination of these factors prohibited its development on the mainland and inner Channel Islands: (1) strong and directly on-shore winds of long duration and persistence, all of which are needed for eolianite development; (2) a coastal configuration which locally permitted large carbonate biomass concentrations; (3) a widely exposed continental shelf directly to the windward of the coast during late Pleistocence time which provided a significant and long-term source of carbonate debris for deflation; (4) an absence of mountainous terrain inland from the coast, which encouraged strong and directly on-shore winds; (5) an absence of rivers or large streams which locally permitted low silica-high carbonate beach sands to accumulate. Of the factors, listed, the first is self-explanatory; the others require further elaboration.

Two paleosols, each underlain by eolianite. The paleosol in the immediate foreground was buried by eolian sand; a second soil subsequently developed over the sand. San Miguel Island.

Regarding the second factor, variations in lithology affect coastal configuration and, under certain conditions, large carbonate biomass concentrations will be encouraged. In southern California, for example, Miocene rocks commonly form resistant headlands, whereas Pliocene and Quaternary rocks generally form embayments and bights. Along a high wave-energy environment such as characterizes the California coast, mollusks thrive on the headlands. When these animals die, their shells are moved by longshore currents to adjacent coves or bights where they may become concentrated. Similarly, beach deposits may become highly calcareous; especially since rivers and large streams, which supply a great deal of the quartz and other noncarbonate fractions to beach sand on the mainland, are not present.

Of prime importance to the formation of eolianite was the supply of calcareous debris exposed to wind erosion by regressional Pleistocene seas. That the eolianite parent material was derived during sea-level lowering is indicated by the eolianites perched on cliffs overlooking shorelines that presently have no exposed beach sands; and by eolianites in some areas that obviously once extended below present sea level. Submarine contours show that wide insular shelves would be exposed to deflation if sea level dropped 300 to 400 feet.

Another factor that may encourage eolianite formation is the absence of high mountainous terrain inland from the coast. Mountains act as barriers to on-shore surface wind and often serve to deflect it parallel to the mountain axis. This is effectively demonstrated by San Miguel and Santa Cruz Islands, both of which have axes oriented east-west, as they are part of the same partially drowned mountain system. Surface winds sweep completely over San Miguel because of its low relief; but on Santa Cruz they are deflected roughly parallel to the longitudinal axis because of that island's high mountainous character. This phenomenon I witnessed one day in July 1966 while sitting atop a mountain peak on Santa Cruz Island. The wind directions were made apparent by occasional patches of fog and mist. (A lowering of sea level by 300 or 400 feet, however, might modify this effect considerably.)

Conditions conducive to eolianite formation on the inner Channel Islands and the mainland either were absent during the late Pleistocene or, if eolianite did form at lower elevations, it was subsequently obliterated by rising post-Wisconsin seas. Finally, one cannot discount the unlikely possibility that calcareous eolianite may be present on the mainland but has not yet been reported.

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Edit. note. One very important reference is missing from the above list. In 1891, C. D. Voy made an extensive study of most of the Channel Islands for the State Mining Bureau (predecessor to this Division). His manuscript on Santa Rosa Island was 48 pages long, typewritten (about 16 pages of printing), with five full-page plates; that on San Miguel Island was 34 pages long (about 12 pages of printing), with 11 full-page plates. Each manuscript considered the history of discovery, climate, anchorage, geology, paleontology, soil, zoology, and flora, among other topics. They were a summary of virtually all that was known of each island.

The plates had already been printed when the Governor, in his message to the Legislature, expressed the opinion that "People will not read long, tedious reports, and if it were not for the condensed statements given out through the press the people of the State generally would have very little information in regard to our public institutions."

For this reason, both of Mr. Voy's reports were deleted from the Report of the State Mineralogist when it was printed in 1893. The manuscripts, insofar as we know, have been lost, and citizens of the past 80 years have been deprived of what would have been exceedingly valuable documents.

We particularly regret the loss of the plates. Hopefully, they would have revealed the progress of soil removal in the 30 years between 1860 and 1890, as well as have given us a clue to the progress since 1890.

As it is, the misuse of the islands, which has transformed arable, forested land into a desert of lifeless stumps, is a plain enough lesson in conservation. Had we not been denied the fruits of earlier research, the lesson might have been even more graphic. —M.R.H.

New Catalog of Educational Films

Encyclopaedia Britannica Educational Corporation has announced that the 1967–68 Catalog of Educational Films is now available.

The catalog contains descriptions of all the 16mm and 8mm motion pictures currently available for purchase from EBEC. The structure of the catalog places special emphasis on the organization of the films by ascending grade level within appropriate major subject areas.

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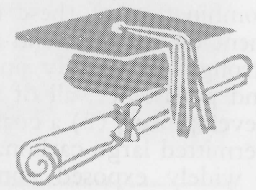

THESES AND DISSERTATIONS

Once again, may we emphasize that we would like, as a public service, copies of any theses or dissertations on earth science in California, or on related subjects (including history of mining, and early landscape artists, among others)? If it is not possible to supply us with a copy, may we please have a copy of the abstract, together with information as to where an interested person might see the entire manuscript?

It is our intention to announce new studies of this nature in this column, so that all of our readers may be informed of them. However, since theses are sent to the Division for a number of reasons (interlibrary loan, state map data, publication in one of our technical series, technical review), it is essential that theses and dissertations sent for our public information file be addressed in this manner:

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Sedimentology of the Sespe Formation, southwestern California. By Ronald C. Flemal. 1966. On file at Princeton University, New Haven, Connecticut, and at the Division of Mines and Geology Library, San Francisco.

Areal geology of the southeast portion, Chanchelulla Peak quadrangle, California. By James Rodell Maytum. 1967. MS thesis, on file at San Diego State College, 113 pp., 2 tables, 6 figs., geologic map (scale 1″ = 2,000′). Abstract on file in the Library, Division of Mines and Geology, San Francisco.